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SEMINAR ON THE CHANGING ROLE OF ELECTROCARDIOGRAPHY IN CLINICAL PRACTICE—II

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Guest Editors

When Is the Vectorcardiogram Superior to the Scalar Electrocardiogram?

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The clinical usefulness of the vectorcardiogram is well documented by the numerous reports published in the last 3 decades. It has been found more reliable than the electrocardiogram for the diagnosis of atrial enlargement and right ventricular hypertrophy. It is more sensitive than the electrocardiogram in the recognition of myocardial infarction, especially if the infarction is inferior or if it occurs in the presence of left bundle branch block or left anterior hemiblock. It is helpful in the diagnosis of ventricular pre-excitation and in the localization of the bypass tract. Some repolarization abnormalities are more clearly demonstrated by the vector display. However, some information, such as that on cardiac chamber size and myocardial damage, can also be obtained by other noninvasive tests that are often performed on the same patients. With the increasing awareness of cost-effectiveness of various laboratory procedures in medicine, the vectorcardiogram should no longer be considered a routine cardiac test and should be requested only for a specific clinical purpose. When properly utilized, vectorcardiography should remain a valuable diagnostic as well as teaching tool.

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A major difference between the conventional electrocardiogram and the vectorcardiogram is the method of display. The conventional scalar electrocardiogram depicts the variation in the magnitude of the electrical potential generated from the heart in relation to time in the 12 or more leads routinely obtained. In vectorcardiography the electrical activity of the heart is represented by a single dipole. The strength and spatial orientation of the dipole at each moment are depicted by a spatial vector. The changing direction and magnitude of the instantaneous vectors during each cardiac cycle are displayed as loops formed by joining the terminals of the vectors. The spatial vector loops are viewed in three mutually perpendicular planes: the transverse, sagittal and frontal planes. It is apparent that the phasic changes of the electrical forces from the heart, especially their directions, are more clearly identified in the vectorcardiogram. The scalar electrocardiogram may be derived from the vectorcardiogram with a reasonable degree of accuracy. The scalar complexes in the limb leads may be obtained by projecting the frontal plane vector loops on the hexaxial reference system based on Einthoven's equilateral triangle, and the complexes in the precordial leads by the projection of the transverse plane vectors on the precordial lead axes. Additional right-sided or posterior chest leads may be derived as needed. On the other hand, the usual form of the vectorcardiogram is a still picture of one cardiac cycle. The scalar electrocardiogram is needed to study cardiac arrhythmias.

Another theoretic advantage of the vectorcardiogram is related to the lead system used for its recording. Because the heart is not located in the center of the human torso, the actual directions of the electrical axes of the conventional electrocardiographic leads are not identical to those that are commonly assumed from the anatomic location of the electrodes. The lead axes of the standard limb leads form a scalene (Burger) rather than an equilateral triangle (1). Fur-

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thermore, electrical potentials of equal strength applied to these leads do not result in deflections of the same magnitude (2). Lead III records the largest voltage and lead I records the smallest. These artifacts prompted the design of several corrected orthogonal lead systems to record the vectorcardiogram, with the Frank lead system being the most commonly used (3). The electrical axes of the X, Y and Z leads are perpendicular to each other. The scalar voltages recorded by each lead are uniform when electrical force of the same strength is applied to each lead.

The clinical value of the vectorcardiogram depends on the amount of information it may supply that is not readily available from the conventional scalar electrocardiogram. The purpose of this paper is to review and compare the diagnostic reliability of the electrocardiogram and vectorcardiogram in some of the major pathologic entities.

Atrial Abnormalities

Left and right atrial enlargement. The electrocardiographic diagnosis of left atrial enlargement is generally based on the findings of an increase in the duration of the P waves, that are often notched in some of the limb leads (the P mitrale pattern), leftward shift of the frontal plane P axis and a prominent negative component of the P wave in lead V_1 (4). Although the equivalent changes may be observed in the vectorcardiogram, the vectorcardiographic diagnosis of left atrial enlargement emphasizes the magnitude of the maximal posterior P vectors in the transverse or sagittal planes (5,6). In 21 consecutive patients with mitral valve disease and angiographically documented left atrial enlargement reported by Benchimol et al. (7), the electrocardiogram was diagnostic or suggestive of left atrial enlargement in 43% and the vectorcardiogram in 86%. In a series (6) of 20 patients with the electrocardiographic findings of the P pulmonale pattern, 10 were found to have vectorcardiographic signs of left atrial enlargement. All 10 patients had clinical evidence of left-sided heart disease only. In the same study only 49 of 100 consecutive patients with the P pulmonale pattern had a disease in which right atrial enlargement might be expected. The results suggested that criteria depending on the P wave voltage and axis in the frontal plane alone have low specificity. This is also true when the increased duration and notching of the P wave are used for the diagnosis of left atrial enlargement (8). These changes may be present in patients with an intra-atrial conduction defect without atrial enlargement due to a condition such as chronic pericarditis, myocarditis and atrial ischemia, infarction or fibrosis (9,10).

The increased sensitivity of the vectorcardiogram in the diagnosis of left atrial enlargement is probably related to the lead system used. Among the electrocardiographic criteria for the diagnosis of left atrial enlargement, a prominent negative component of the P wave in lead V_1 has been found most reliable (11). However, because the electrode for lead V_1 is in close proximity to the right atrium, prominent electrical forces from the enlarged but posteriorly located left atrium may be masked. A similar problem is less likely to occur with the corrected lead system used to record the vectorcardiogram.

Ventricular Hypertrophy

Left Ventricular Hypertrophy

The electrocardiographic and vectorcardiographic recognition of left ventricular hypertrophy are based mainly on the increased magnitude of the QRS forces directed leftward and posteriorly. Secondary repolarization abnormalities, if present, give additional support to the diagnosis. Romhilt et al. (12) were able to identify by the vectorcardiogram 61% of 70 hearts with anatomic left ventricular hypertrophy in an autopsy series. No false positive diagnoses were made among 23 hearts without left ventricular hypertrophy. In a larger series reported by Dower and Horn (13), the vectorcardiogram recognized 41.7% of autopsy proved cases of left ventricular hypertrophy with 11.4% false positive diagnoses. In each series the overall accuracy of the vectorcardiographic diagnosis was similar to that of the electrocardiogram. In a study of 100 autopsy-proved cases of left ventricular hypertrophy reported by Abbott-Smith and Chou (14), the vectorcardiogram was less sensitive than the electrocardiogram when the voltage criteria alone were used. A correct diagnosis of left ventricular hypertrophy was made in 33% with 11.7% false positive diagnoses. The electrocardiogram was able to recognize 41.9% of the hearts with left ventricular hypertrophy, with a false positive diagnosis in 8.8%. When other QRS changes and the ST vector and T loop abnormalities were also utilized, however, the vectorcardiogram recognized 50% of the cases without an increase in false positive diagnoses.

From the available data it appears that the vectorcardiogram is less sensitive than the electrocardiogram in the diagnosis of left ventricular hypertrophy. The attenuation of the voltage obtained from the C electrode (which is located near the cardiac apex) in the recording of the X lead of the Frank lead system is probably responsible for some of the false negative diagnoses related to the voltage criteria. On the other hand, the morphologic changes in the QRS loop may be useful in improving the specificity of the diagnosis, especially in younger patients in whom the voltage criteria alone are not reliable. In the transverse plane, there is a leftward displacement of the initial and terminal deflections of the loop and its distal area is larger than the proximal area. These are some of the typical vectorcardiographic changes seen in left ventricular hypertrophy that are not easily identifiable in the scalar electrocardiogram (14). Gaum et al. (15) analyzed the vectorcardiogram and electrocardiogram in patients with supravalvular aortic stenosis and coarctation of the aorta. They observed a characteristic transverse plane QRS loop in 7 of 8 patients with supravalvular aortic stenosis and 10 of 21 patients with coarctation of the aorta. The initial forces were displaced leftward and anteriorly, whereas the maximal QRS vectors were directed rightward and posteriorly. When these congenital defects are clinically suspected, the vectorcardiogram gives additional support to the diagnosis. It was postulated that the vectorcardiographic pattern may reflect hypertrophy of the posterobasal portion of the left ventricle, or that the changes were a manifestation of left posterior hemiblock (15).

Right Ventricular Hypertrophy

Conventional electrocardiographic criteria. In normal adults the electrical forces generated from the right ventricle are masked by the dominant left ventricular potential. The increased anterior and rightward forces due to right ventricular hypertrophy may or may not alter the ventricular complex suffficiently to be detectable in the electrocardiogram or vectorcardiogram. The electrocardiographic diagnosis of right ventricular hypertrophy is based mainly on the degree of right axis deviation of the QRS complex in the frontal plane, the amplitude of the R wave in right precordial lead V_1 and the S waves in left precordial leads V_5 and V_6 and the R/S ratio in these leads. The sensitivity of the electrocardiogram in the diagnosis of right ventricular hypertrophy is relatively low in an unselected adult population (16). In a carefully studied autopsy series Scott (17) observed a pattern of right ventricular hypertrophy in 32% of 47 cases of isolated right ventricular hypertrophy. The sensitivity is even lower when anatomic left ventricular hypertrophy coexists, or the right ventricular hypertrophy develops as a result of left ventricular disease (16). In adult patients with right ventricular hypertrophy supported by hemodynamic data the hypertrophy was recognized by the electrocardiogram in 66% (18). In contrast, in children with tetralogy of Fallot the electrocardiographic diagnosis of right ventricular hypertrophy was made in as many as 100% (19).

In an extensive anatomic study involving 719 unselected hearts. Flowers and Horan (20) found that none of the commonly used individual electrocardiographic criteria for the diagnosis of right ventricular hypertrophy had a sensitivity greater than 28%. Those criteria having a higher sensitivity utilized the increase in the amplitude of the S waves in the left precordial leads. They were also the criteria that gave the highest number of false positive diagnoses. Changes that are highly specific for the diagnosis (for examples, qR pattern in lead V_1) had a very low sensitivity (5%) (20). Their results confirmed the earlier observations by Roman et al. (21). In that study a false positive diagnosis was made in 60% of the 118 cases that met one or more of the conventional electrocardiographic criteria for right ventricular hypertrophy.

Vectorcardiographic criteria. In the vectorcardiogram three types of transverse plane QRS loop configurations may be distinguished in right ventricular hypertrophy (22). Type A right ventricular hypertrophy presents a clockwise QRS loop displaced anteriorly and rightward, type B presents an anteriorly displaced counterclockwise loop and type C presents a right posterior counterclockwise loop. Usually, type A is associated with the most severe degree of anatomic right ventricular hypertrophy and type B with the least severe (23,24).

The quantitative vectorcardiographic criteria for the diagnosis of right ventricular hypertrophy are generally based on the increased rightward voltage, the direction of the half area or maximal QRS vector and the distribution of the QRS loop area in the various quadrants (18,25–29). Chou et al (18) considered right ventricular hypertrophy to be present if the QRS loop area in the anterior and rightward quadrant of the transverse plane is greater than 70% of the total, or if the area in the right posterior quadrant is greater than 20% of the total. Right ventricular hypertrophy is also suggested if the QRS loop area in the right inferior quadrants of the frontal plane is greater than 20% of the total. Among 97 patients with atrial septal defect, mitral stenosis or chronic obstructive lung disease with pulmonary hypertension, 80 (83%) met one or more of these criteria, whereas the conventional electrocardiogram was suggestive of right ventricular hypertrophy in 64 (66%). The specificity of these electrocardiographic criteria was, however, not tested. In 32 patients with chronic obstructive lung disease, Wilson et al. (30) found that a right posterior or right inferior quadrant QRS loop area of 15% or more identified patients with pulmonary hypertension with a sensitivity of 81% and a specificity of 90%. None of the 32 patients had electrocardiographic evidence of right ventricular hypertrophy. Curtiss et al. (24) correlated the hemodynamic data with the vectorcardiographic findings in 207 patients with right ventricular overload due to mitral stenosis, cor pulmonale and various congenital heart diseases; 219 patients without pulmonary hypertension served as control subjects. The investigators found that when the QRS loop area in the right posterior or right inferior quadrant was greater than 20% of the total, the vectorcardiogram identified pulmonary hypertension (mean pulmonary artery pressure greater than 25 mm Hg) or significantly increased pulmonary to systemic flow ratio (greater than 1.5) with a sensitivity of 79% and a specificity of 89%. In patients with a clockwise transverse plane QRS loop (type A), severe pulmonary hypertension with a mean pulmonary artery pressure greater than 50 mm Hg was usually present.

Cowdery et al. (31) suggested that right ventricular hypertrophy is present if the transverse plane QRS loop has 1) a maximal transverse magnitude of less than 1.8 mV, and 2) the QRS vector at $-45°$ is less than 0.3 mV, or the maximal anterior amplitude plus the maximal rightward amplitude minus the amplitude at $-45°$ is equal to or greater than 0.5 mV. When these criteria were applied in 84 patients with hemodynamically significant mitral stenosis and 324 normal subjects or patients with normal hemodynamic findings, the sensitivity of the criteria in recognizing right ventricular hypertrophy was 60%, compared with a value of 27% with the conventional electrocardiogram. The specificity of the vectorcardiographic and electrocardiographic criteria was similar (96 and 98%, respectively).

From the available data it appears that the vectorcardiogram is superior to the electrocardiogram in the recognition of right ventricular hypertrophy. However, it is not more specific. A false positive vectorcardiographic diagnosis of right ventricular hypertrophy occurs most frequently in cases with a type B configuration. It is well known that true posterior myocardial infarction may cause anterior displacement of the QRS loop. Similar changes may occur in "anterior conduction defect" because of disease of the anterior or septal fascicle of the left bundle branch (32–34). An increase in the right inferior QRS forces may occur in left posterior hemiblock, which is known to mimic the right axis deviation seen in right ventricular hypertrophy.

Diagnosis of right ventricular hypertrophy in the presence of bundle branch block. The electrocardiographic diagnosis of right ventriular hypertrophy in the presence of complete right bundle branch block is difficult and unreliable (35,36). Baydar et al. (37) found that in patients with right bundle branch block the incidence of right ventricular hypertrophy or chronic obstructive lung disease is highest when the entire QRS loop in the transverse plane vectorcardiogram is inscribed clockwise. Fedor et al. (38) studied the vectorcardiogram in 243 patients with right bundle branch block. They found that 84% of the 31 patients with an anterior and clockwise transverse plane QRS loop had heart failure or severe pulmonary disease, whereas none of the 36 patients with otherwise normal findings on cardiovascular examination had such a pattern. In a study of 30 patients with right ventricular hypertrophy due to congenital heart disease before and after corrective surgery, Chou et al. (39) found that the development of right bundle branch block in these patients did not significantly alter the main body of the QRS loop. In 25 of the 30 patients right ventricular hypertrophy was recognized by using the direction of the maximal QRS vector, the maximal rightward QRS forces and the R/S ratio in lead X. These same measurements resulted in no false positive diagnoses of right ventricular hypertrophy when they were applied to nine patients with right bundle branch block but without right ventricular hypertrophy. In a similar study of 48 patients with and 25 patients without right ventricular hypertrophy, Brohet et al. (40) found that the vectorcardiogram was more sensitive and specific than the electrocardiogram in the detection of right ventricular hypertrophy in the presence of right bundle branch block.

Right ventricular hypertrophy in the presence of left bundle branch block. Very limited information is available in regard to the electrocardiographic or vectorcardiographic diagnosis of right ventricular hypertrophy in the presence of left bundle branch block. In a few cases we noted (41) a rightward displacement of the QRS loop in the transverse plane, although the overall configuration of the QRS loop remained essentially unchanged.

Myocardial Infarction

The electrocardiographic diagnosis of transmural myocardial infarction is based on the appearance of abnormal Q waves in leads corresponding to the location of the infarcted area. The exception is true posterior myocardial infarction, in which the abnormal finding is a tall and broad R wave in lead V_1. This reciprocal change is used for the diagnosis because the conventional electrocardiogram does not include posterior chest leads.

Limitations of conventional electrocardiography. Because ventricular depolarization begins at the interventricular septum and the various areas of ventricular myocardium are not activated simultaneously (42), one would not theoretically expect that myocardial necrosis always alters the initial QRS forces. The inherent limitations of the conventional electrocardiographic criteria in the diagnosis of myocardial infarction are, therefore, quite apparent. Because the phasic changes and abnormalities of the mid- and late QRS forces are more easily identified in the vectorcardiographic display, such changes have been utilized with advantage in the vectorcardiographic recognition of myocardial infarction.

In the absence of an intraventricular conduction defect, the overall sensitivity of the electrocardiogram in the diagnosis of myocardial infarction based on more recently reported autopsy series varies from 55 to 61% (43,44). If the infarction is acute, 75 to 94% of the cases may be correctly recognized (45–47). Conversely, up to 80% of patients with old infarction may not have diagnostic electrocardiographic abnormalities (45). Anterior myocardial infarction is generally more easily recognized than inferior, true posterior or high lateral myocardial infarction (44,48–50). The difficulty in the electrocardiographic diagnosis of subendocardial infarction, multiple infarctions or myocardial infarction in the presence of left ventricular hypertropy is well known (45,50). Abnormal Q waves may also be seen in the absence of anatomic evidence of myocardial necrosis. The reported incidence of a pseudoinfarction pattern in autopsy series varied from 11 to 31% (43,44). The percent of false positive diagnoses was high (46%) when the abnormal Q waves were limited to leads V_1 to V_4 or to the inferior leads alone, but was low (4%) when they were located in leads V_5 and V_6, or both the anterior and inferior leads (44).

Advantages of vectorcardiography. In a study of 98 cases of myocardial infarction proved at autopsy, Wolff et al. (51) were able to diagnose myocardial infarction in 63 cases by the vectorcardiogram but in only 48 cases by the electrocardiogram. Similar results were obtained later by many investigators (52–57). The sensitivity of the various vectorcardiographic criteria for the diagnosis of myocardical infarction proved anatomically or clinically varied from 77 to 94%, compared with a sensitivity of 66 to 70% by the conventional electrocardiogram. The incidence of a false positive vectorcardiographic diagnosis of myocardial infarction ranged from 3 to 31%. It was similar to that of the electrocardigoraphic criteria when they were applied to the same group of patients.

The vectorcardiogram is particularly helpful in the diagnosis of inferior myocardial infarction. As described by Young et al. (56), the initial QRS forces in some cases of inferior myocardial infarction may be directed downward and are followed by superior displacement of the succeeding part of the QRS loop. In such instances, R instead of Q waves will be recorded in the inferior leads II, III and aVF of the conventional electrocardiogram. Other vectorcardiographic signs of inferior infarction that are not readily apparent in the scalar electrocardiogram include 1) a clockwise frontal plane QRS loop with the maximal QRS vector superior to 10°, 2) leftward shift of the point of intersection between the QRS loop and X axis, and 3) deformities or bites in the afferent limb of the QRS loop (56–60). Hurd et al. (61) recently evaluated the various vectorcardiographic criteria proposed for the diagnosis of inferior myocardial infarction in 146 patients who underwent cardiac catheterization. They found that the overall accuracy of the vectorcardiogram was 90% versus 62% for the scalar electrocardiogram. The difference was due to the higher sensitivity of the vectorcardiogram. The vectorcardiogram has also been shown to be superior to the electrocardiogram in the prediction of severe dyskinesia in patients with inferior myocardial infarction (62). Serial measurements of the magnitude of the maximal spatial QRS vector were reported to be useful in the estimation of the infarct size in patients with acute myocardial infarction irrespective of the location (63).

Diagnosis of myocardial infarction in the presence of intraventricular conduction abnormalities. *Right bundle branch block.* Theoretically, right bundle branch block should not interfere with the electrocardiographic and vectorcardiographic diagnosis of anterior, inferior or lateral myocardial infarction. The initial QRS forces are not expected to be altered in isolated right bundle branch block. In 36 autopsy cases of myocardial infarction and right bundle branch block, Horan et al. (64) observed abnormal Q waves of more than 0.03 seconds duration in 72%. In 40 cases of right bundle branch block without myocardial infarction, a false positive electrocardiographic diagnosis of myocardial infarction was made in 25%. Goldman and Pipberger (65) were able to identify correctly with the orthogonal electrocardiogram and vectorcardiogram 54% of 95 cases of myocardial infarction with a coexisting right ventricular conduction defect. A false positive diagnosis was made in 11% of 131 cases of right ventricular conduction defect without myocardial infarction. Because of the anterior displacement of the mid and late QRS forces in uncomplicated right bundle branch block, the diagnosis of true posterior myocardial infarction is difficult when the conduction defect is present. Anterior displacement of the body of the QRS loop or the absence of an S wave in lead V_1 may occur in the absence of myocardial infarction or as a result of right ventricular hypertrophy, pulmonary disease or left ventricular conduction defect (33,38,66).

Left bundle branch block. In this conduction defect the markedly altered sequence of ventricular activation renders the diagnosis of myocardial infarction by the conventional electrovectorcardiographic criteria more difficult. In an evaluation of the criteria proposed by various authors, Scott (66) found that in 85 autopsy cases of left bundle branch block, Q waves of 0.04 second or longer in leads I, V_5 and V_6 were the most reliable signs of myocardial infarction. In the ventorcardiogram, these changes have as their counterpart a rightward displacement and clockwise rotation of the initial forces of the QRS loop in the transverse plane that were found to be highly specific for the diagnosis of myocardial infarction (65,67,68). Other findings that are atypical for the "classical" left bundle branch block configuration that are highly suggestive of myocardial infarction include rightward displacement of the afferent limb of the QRS loop, the absence of any initial anterior forces, anterior direction of the 0.275 second vector and distortion of the QRS loop, especially in its afferent limb (69,70). Some of these changes may not be readily demonstrable by the scalar electrocardiogram. Most of the electrovectorcardiographic and pathologic correlation studies supported the view that the vectorcardiogram is superior to the electrocardiogram in the diagnosis of myocardial infarction in the presence of left bundle branch block, although the ability of the vectorcardiogram in the localization of the infarction is also limited (67–70).

Left anterior hemiblock. In left anterior hemiblock the scalar electrocardiogram typically displays an rS complex in the inferior leads. In some instances the r waves are diminutive or absent and the question of inferior myocardial infarction may be raised. In the vectorcardiogram the characteristic findings of uncomplicated left anterior hemiblock consist of small initial QRS forces directed inferiorly and rightward. This is followed by a marked superior and leftward displacement of the remainder of the frontal QRS loop. The entire QRS loop is inscribed counterclockwise (22).

When left anterior hemiblock is complicated by inferior myocardial infarction, the rotation of the initial deflection or of the efferent limb of the QRS loop, or both, become clockwise, with the rest of the QRS loop remaining counterclockwise. These characteristic changes are easily recognizable (22,71–73). In the scalar electrocardiogram the inferior leads may or may not display an R wave or slurring of the downstroke of the S wave.

Ventricular Pre-excitation

The electrocardiographic diagnosis of ventricular pre-excitation is based on the presence of a short P-R interval, delta wave and wide QRS complex. In about 12% of the cases the P-R interval may be greater than 0.12 second (74,75). In some of these cases the anomalous ventricular excitation is by way of the Mahaim fibers (nodoventricular or fasciculoventricular fibers) (76–78). The differentiation of this variant form of ventricular pre-excitation from bundle branch block, especially left bundle branch block, becomes difficult. In the vectorcardiogram the delta wave is displayed as a slowly inscribed initial deflection of the QRS loop having a duration of 0.02 to 0.07 second (22,79). Such initial conduction delay is not seen in bundle branch block but is observed in ventricular ectopic beats or pacemaker-induced beats (80–83). The differentiation of ventricular pre-excitation from ectopic ventricular complex usually does not constitute a practical problem.

Localization of the bypass tract. With the advent of surgical treatment of patients with ventricular pre-excitation and tachyarrhythmias (the Wolff-Parkinson-White syndrome), precise localization of the bypass tract becomes an important issue. Type A Wolff-Parkinson-White syndrome, with the delta wave in the electrocardiogram primarily upright in all the precordial leads, is generally associated with a left-sided accessory bundle (84–86). Type B Wolff-Parkinson-White syndrome, in which the delta wave and the remainder of the QRS complex are negative in leads V_1 and V_2, is associated with a right-sided bypass (84,86). When the delta waves are negative in leads V_5 and V_6 (type C Wolff-Parkinson-White syndrome), the area of pre-excitation is always in the lateral free wall of the left ventricle (84). The electrocardiogram, however, is not able to discriminate between the free wall and septal accessory pathways. In the vectorcardiogram the delta deflection is generally oriented anteriorly in type A, leftward and posteriorly in type B and rightward in type C Wolff-Parkinson-White syndrome. In patients with a single accessory pathway, Tonkin el al. (86) found that a superior orientation of the 10 ms vector is strongly suggestive of a septal bypass tract, whereas an inferior orientation of this vector suggests a free wall bypass. A strong correlation between the superior orientation of the initial 10 and 20 ms vectors and a paraseptal or septal location of the bypass was also observed recently by Talwar et al. (87).

Pre-excitation with ventricular hypertrophy. As in other forms of ventricular conduction defect the electrocardiographic diagnosis of ventricular hypertrophy in the presence of ventricular pre-excitation is difficult. In a vectorcardiographic study of pre-excitation in children, Miller and Victorica (88) found that when the axes of the delta deflection and the main QRS complex are more or less parallel, congenital heart disease is usually absent. In contrast, congenital heart disease with right ventricular hypertrophy is usually present if the delta vectors are directed posteriorly but the main QRS vector is anterior. Left ventricular hypertrophy is usually present if the delta vectors are oriented anteriorly and the main QRS vector is oriented posteriorly.

Repolarization Abnormalities

Minor ST segment displacement is usually more easily detected in the scalar tracing. In patients with acute myocardial infarction, precordial mapping of the ST segment has been found useful in the evaluation of the extent of myocardial injury (89). Both experimental and clinical observations, however, suggest that the same information may be obtained from the magnitude and direction of the ST vector. The vectorcardiogram can be used as a simple and accurate substitute for the more time consuming mapping procedure (63,89,90).

The loop. In the scalar electrocardiogram, abnormalities of the T waves are manifested by their changes in amplitude, polarity or configuration. The normal T wave is asymmetric. Whether it is upright or inverted, its first half has a more gradual slope than the second half. The amplitude and polarity of the T wave are related to the magnitude and direction of the maximal T vector in the vectorcardiogram. The relatively slow speed of inscription of the efferent limb of the T loop is the counterpart of the gradual slope of the first half of the T wave. In certain pathologic states, such as myocardial ischemia, the speed of inscription of the T loop may become uniform. Symmetric T waves, however, may or may not be seen in the scalar leads. There are also other characteristics of the T loop that are not readily apparent in the scalar electrocardiogram. The normal spatial T loop is elliptical in shape; it is elongated and its length to width ratio is 2.6:1 or greater (91). Abnormally wide T loops are seen in patients with acute myocardial infarction or myocardial ischemia. They are also seen in patients with old myocardial infarction in whom the T waves in the scalar electrocardiogram have returned to normal. However, a wide T loop is not a specific finding for ischemic heart disease; it is also observed in patients with left or right ventricular hypertrophy and ventricular conduction defects.

Except when it is very narrow, the normal T loop is inscribed counterclockwise in the transverse plane and clockwise in the right sagittal plane. In the frontal plane the rotation is variable. Abnormal clockwise rotation of the transverse plane T loop may be seen in patients with ventricular hypertrophy and bundle branch block as well as ischemic heart disease. It is particularly common in patients with right ventricular hypertrophy and right bundle branch block (22). This finding is often useful in patients with a normal QRS complex and T wave inversion in the right precordial leads. Such T wave inversion may represent a persistent juvenile pattern in a relatively young person, or may be due to anterior myocardial ischemia or right heart strain. A clockwise inscription of the horizontal plane T loop in such cases is highly suggestive of the presence of organic heart disease (92). Kuo and Surawicz (93), however, questioned the value of this finding because they observed it also in apparently normal persons.

Conclusions

The value of the vector concept in the teaching of electrocardiography is unquestionable. The clinical usefulness of the vectorcardiogram is documented by the numerous reports published in the past 3 decades and is summarized in most of the major modern textbooks in general cardiology and vectorcardiography and in review articles (22,94–104). With the increasing awareness of cost-effectiveness of the various laboratory procedures in medicine, the indications for requesting a vectorcardiogram in clinical practice need to be reassessed. From the preceding discussion it appears that the vectorcardiogram is superior to the electrocardiogram in the diagnosis of atrial enlargement and right ventricular hypertrophy. It is more sensitive than the electrocardiogram in the recognition of myocardial infarction, especially if the infarction is inferior or if it occurs in the presence of left bundle branch block or left anterior hemiblock. It is useful in the diagnosis of ventricular pre-excitation when the PR interval is within the normal range. It is also helpful in the localization of the site of the bypass tract in this pre-excitation syndrome. Some repolarization abnormalities are more clearly demonstrated by the vector display. On the other hand, some vectorcardiographic information, such as that on chamber size and myocardial damage, can also be obtained by other noninvasive tests. Echocardiography and radionuclide imaging techniques are often performed in the evaluation of cardiac patients. Therefore, the vectorcardiogram should no longer be considered a routine cardiac test and should be requested only for a specific purpose as the clinical circumstance dictates. With modern technology it is also quite possible that additional electronic circuitry may be added to the routine electrocardiograph, and vector loops may be plotted as part of the tracing. Under such circumstance, valuable additional information may be obtained with minimal extra cost to the patient.

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